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United States Department of Agriculture,
DIVISION OF ENTOMOLOGY.

THE USE OF HYDROCYANIC ACID GAS FOR FUMIGATING GREENHOUSES AND COLD FRAMES.

IMTRODUCTION.

The most widely used insecticide for greenhouse fumigation is tobacco in its various forms. In many instances it is without doubt the cheapest and safest insecticide to use against plant-lice and a few other greenhouse insects. Its effectiveness, however, under the best conditions is not great, as it requires repeated use at short intervals. Moreover, it may cause serious injury to the plants. In the case of violets it has been found to be of only slight value against plant-lice working in the bud, and while it may destroy the so-called "green aphis" when exposed, it is not effective in killing the "brown aphis." On the other hand, tobacco may prove injurious to the foliage and flowers, bringing on epidemics of "spot." Tobacco is also useless against scale insects in general and mealy bugs. The desirability of some insecticide as easy to use as tobacco but more penetrating and effective and less likely to injure plants was apparent, and became absolutely necessary in our study of the diseases of certain crops.

Hydrocyanic acid gas, since its introduction by the Division of Entomology in 1886 as a remedy against scale insects of the orange, has proved of great value as an insecticide. Previous to our experiments early in 1895, though it had been occasionally tried in greenhouses, hydrocyanic acid was not recommended on account of its injurious effects upon plants. As a result of a series of careful experiments we found that, as a rule, plants were less injured by a short exposure to a relatively large amount of gas than they were by a long exposure to a relatively small amount. On the other hand, a strong dose for a short time was the most effective in killing insects. Different species and varieties of plants, however, were found to vary remarkably in their

EXPLANATORY NOTE.—The fact that a circular of the Division of Entomology should be written by expert employees of the Division of Vegetable Physiology and Pathology needs a word of explanation: Messrs. Woods and Dorsett in the course of their investigations of the diseases of greenhouse plants, found it necessary to destroy the insects living upon the plants which they had under observation. For this purpose they used hydrocyanic acid gas and thus became by this practical experience so well fitted to discuss this particular phase of the use of this important gas that I have requested them to prepare this circular.—L. O. HOWARD, *Entomologist.*

power of withstanding the poison. This in many cases appeared to depend upon the open or closed condition of the breathing pores as well as upon peculiarities of the cell contents. Fumigation an hour or two after sundown, with the temperature as low as practicable, was found to give the best results. In all cases the foliage must be perfectly dry or it may be injured by the gas. In each case the proper amount of gas to use and the length of exposure must be determined by experiment. It is impossible at present to give a general rule applicable to all plants in all stages of development. When the conditions are once determined they must be strictly followed to insure the greatest success. Methods of experimenting will be described in the latter part of this circular. The quantity of gas in each case is always given in terms of the potassium cyanide from which it is made, and on a basis of a cubic

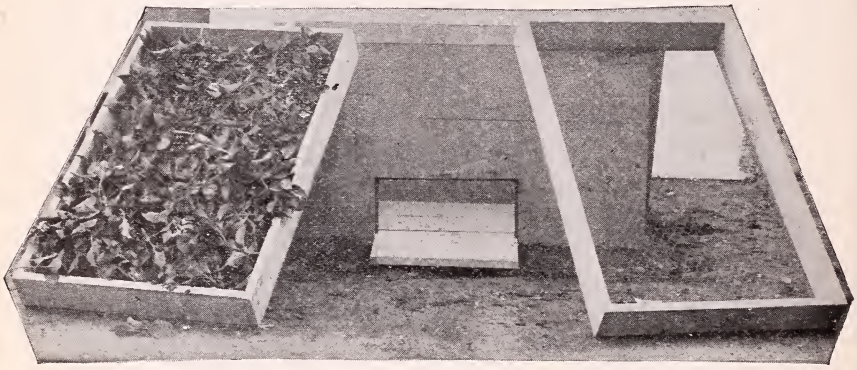

FIG. 1.—Fumigating box showing trays and coleus cuttings (original).

foot of space, as will be explained more in detail further on. The cyanide, as well as the gas made from it, is exceedingly poisonous, and both must be used with the greatest care.

CROPS AND PESTS ON WHICH THE GAS HAS BEEN SUCCESSFULLY USED.

Ferns.—For *Davallia mooreana* infested with a scale insect (*Chionaspis* sp.), 0.075 gram of 98 per cent potassium cyanide should be used for each cubic foot of space to be fumigated, not deducting the space occupied by the plants. Length of exposure, twenty minutes.

One hundred and fifty to two hundred plants with fronds in all stages of development have been thus treated two or three times each year for the past four years with no injury to the plants and almost complete destruction of the insect. They were treated fifty at a time in a fumigating box (fig. 1), described later.

Adiantum cuneatum and *A. Ballii* have been tried on a small scale and were not injured by the treatment.

Coleus.—"Golden Bedder," "Verchaffeltii," "Shylock," and others. 24,000 plants in pots, badly infested with the "white-tailed" mealy bug *(Orthezia insignis).* The house contained 15,587 cubic feet of space. Treated at the rate of one-tenth of a gram of 98 per cent cyanide of potassium per cubic foot of space for twenty minutes, one hour after dark. Orthezia all killed and plants not injured in the least. All other means of destroying the Orthezia had been tried without effect. Large numbers of the common mealy bug were also killed by this treatment; but it was not nearly so effective as for the "white-tailed" mealy bug. All coleus cuttings made by the United States Propagating Gardens for the past two years have been fumigated before being prepared for the cutting bed (see fig. 1).

Double English violets.—"Marie Louise," "Lady Campbell," and others. For plant-lice and general fumigation fifteen-hundredths of a gram of 98 per cent cyanide of potassium for each cubic foot of space is required. The exposure, if made according to directions, will not hurt the plants in any stage of growth. The gas has been used on a large scale in fumigating violets for the past three years with the greatest success, only a few treatments during the season being required. Length of exposure twenty to thirty minutes. Leaf-eating larvæ, slugs, millipedes, cutworms, etc., when exposed are killed as well as plant-lice. Red spiders, however, are not entirely eradicated by the treatment. The foliage of single violets like California and Princess of Wales are sometimes slightly injured by the stronger dose of gas. A weaker dose (one-tenth of a gram potassium cyanide per cubic foot) should be used when they are to be treated.

Other plants.—Other plants on which the gas has been tried on a small scale indicate that it may probably have quite a wide range of usefulness.*

Roses.—"Perle des jardins," "Mermet," and "Bride." The young growth on roses is particularly sensitive and has been more or less injured in all our experiments.

Carnations.—Scott, Garfield, Meteor, and McGowan will stand one-tenth of a gram 98 per cent cyanide per cubic foot of space for 15 minutes without material injury. This will kill about 90 per cent of the

*The gas has been used on the following plants at the rate of one-tenth gram of cyanide per cubic foot of space for twenty minutes without injury. Further experiment, however, is necessary before the treatment can be recommended for these: *Alocasia Macrorhiza variegata; Anthurium crystallinum; Areca lutescens; Aralia filicifolia; Adiantum cuneatum; Adiantum Ballii; Campylobotrys refulgens; Cissus discolor; Crotons* (in variety); *Cichorium intybus; Diffenbachia Lenmanii; Ficus elastica; Fuchsias* (in variety); *Jacaranda mimosæfolia; Marantas* (in variety); *Nymphœa candidissima,* and *odorata rosea; Pontederia crassipes; Pandanus veitchii; Phrynium variegatum; Phyllotœnium Lindenii; Panax Victoriæ; Stenanthium Lindenii.*

plant-lice, but will not kill thrips. The use of the gas for carnations needs to be more carefully investigated before it is recommended. The same is true of chrysanthemums, on which it has been tried with only partial success, the young growth being very sensitive.

Grapes under glass.—The gas has been used with success in New Zealand* for mealy bugs (*Dactylopius adonidum* L.) at the rate of one-third of an ounce 98 per cent cyanide to 100 cubic feet. This is equivalent to nine-hundredths gram per cubic foot. The gas is liberated after dark and left in till next morning, when thorough ventilation is given. It largely escapes, however, during the night. The treatment is said not to injure the plants in the least.

Tomatoes.—Dr. Jabez Fisher, in "American Gardening" (Oct. 29, 1898), reports using the gas for "white fly" (*Aleyrodes* sp.) on tomatoes. The gas from one ounce of pure cyanide of potassium for each 1,000 cubic feet left in the house over night killed all the insects without injury to the plants. This method has not yet proved successful with us in any case, but it should nevertheless receive careful trial by other experimenters.

CUBIC CONTENTS OF THE HOUSE.

It is necessary in every case to determine with great care the cubic contents of the house, frame, or box in which the fumigation is to be made. To illustrate: Fig. 2 shows cross sections of two styles of greenhouse structures now in general use. At the left is an even span house 100 feet long, 12 feet wide. 2 feet on the sides, and 5 feet 6 inches from the surface of the beds to the ridge, with a walk 14 inches wide and 15 inches deep. To determine accurately the number of cubic feet in this or a house of similar construction: *First*, make a rough drawing showing a cross section of the house; *second*, divide the space into triangles and rectangles by drawing a line connecting the two wall plates and one from the ridge at right angles to this; mark on each its respective length in feet and inches. Compute the number of cubic feet in each of the rectangles and triangles in accordance with the following method. In the even span house shown at the left the number of cubic feet of space in the walk is found by multiplying the width by the depth by the length, thus: Multiply 1 foot 2 inches by 1 foot 3 inches by 100 feet; reducing to inches we have 14 inches multiplied by 15 inches by 1,200 inches equals 252,000 cubic inches; dividing this result by 1,728, the number of cubic inches contained in a cubic foot, we have 145.83 cubic feet. The rectangle A D G F is computed in the same way, except that in this case it is not necessary to reduce the feet to inches. It would be 12 feet multiplied by 2 feet by 100 feet equals 2,400 cubic feet. This brings us to the triangles. The rule generally given for calculating the

*Fourth Report, Dept. of Agr., New Zealand. 1896. Pp. 141–143.

area of a right-angle triangle is to multiply the base by the perpendicular and divide the product by 2. The result multiplied by the length of the house will give the number of cubic feet the triangular portion contains. For example, taking the triangle A C E; 6 feet multiplied by 3 feet 6 inches, equals 21 feet, divided by 2 equals 10.5 feet, multiplied by 100 feet equals 1,050 cubic feet. The area of the triangle E C D and the cubic feet in this part of the house are determined in the same way; or, in this case, since the triangles are equal, the desired result is obtained by multiplying the number of cubic feet in the triangle A C E by 2; 1,050 multiplied by 2 equals 2,100 cubic feet. The contents of this house is therefore 145.83 plus 2,400 plus 2,100, equals 4,645.83 cubic feet; this result multiplied by the required dose per cubic foot of space will give the amount of cyanide of potassium necessary for one fumigation.

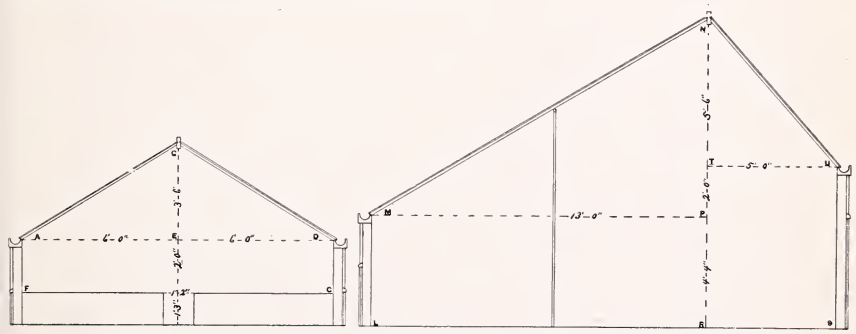

FIG. 2.—End section of even span house at left, same of three-quarter span house at right (original).

Fig. 2 shows at the right a cross section of a three-quarter span house 100 feet long, 18 feet wide, front wall 4 feet 4 inches, back wall 6 feet 4 inches, and 11 feet 10 inches to the ridge. The cubic contents of this house is determined in the same manner, except that the two triangles being unequal, each one will have to be calculated separately. The house contains 15,050 cubic feet. It will thus be seen that the cubic contents of a house or frame of any style can be readily determined by simply dividing a cross section of the same into the necessary number of triangles and rectangles and calculating as demonstrated above.

A simpler method of obtaining the cubic contents of a house has been described by Galloway. This consists in laying off a cross section of the house according to scale, on a piece of paper ruled in squares, each square being equal to a square foot. For example, suppose the squares are one-eighth of an inch to a square foot. The end-section of the house is then accurately laid off on these squares, and by counting the squares and parts of squares the number of square feet of space in the end section can be easily determined. This, multiplied by the length of the house will give the cubic contents in cubic feet.

AMOUNT OF POTASSIUM CYANIDE TO USE.

After the number of cubic feet in the space to be fumigated is determined, the amount of cyanide required is found by multiplying the cubic contents by the dose per cubic foot. For example, if single violets are to be fumigated the dose would be one-tenth of a gram per cubic foot. A dose, therefore, for the even span house, containing 4,646 cubic feet would be 4,646 multiplied by .1 equals 464.6 grams. To reduce this to ounces, divide the number of grams by 28.35 (the number of grams in an ounce avoirdupois). 464.6 divided by 28.35 equals 16.38 ounces avoirdupois. It may be necessary to reduce the fraction of ounces to grains; 437.5 (the number of grains in an ounce) multiplied by .38 equals 166 grains.

If double violets are to be fumigated the cubic contents would be multiplied by .15, thus: 4,646 multiplied by .15 equals 696.9 grams, divided by 28.35 equals 24.58 ounces avoirdupois. .58 ounce equals 253 grains. In the case of a small space of less than 150 cubic feet the dose in grams should first be determined, and this, if necessary, can be changed to grains by multiplying the number of grams by 15.43 (grains in a gram), thus: 30 (cubic feet) multiplied by .15 grams equals 4.5 grams, multiplied by 15.43 (grains in a gram) equals 69.435 grains, or approximately 69.5 grains. The reduction to ounces or grains will not be necessary if metric weights are used, which is strongly urged. When the dose for certain plants in a given house, frame, or box is once obtained, it should be carefully recorded on the house or box thus:

Contents: 1,015 cubic feet.

{ Ferns, .075 gram per cubic foot equals 76.1 grams.
{ Violets, double, at .15 gram per cubic foot equals 152.25 grams.

If a scale weighing with avoirdupois weights is used, the dose should be recorded in ounces and grains.

SELECTING A TIME TO FUMIGATE.

Care should be taken to select a night when the houses can be ventilated the required time without injury to the plants and when there is no likelihood of rain.

PREPARATION OF THE HOUSE FOR FUMIGATION.

On account of the very poisonous nature of the gas, it is necessary to arrange a number of ventilators, the more the better, so that they can be easily opened from the outside. It would be very dangerous to enter the house while it contains the gas. All broken glass should be replaced and holes stopped up; a thoroughly wet piece of newspaper will close a crack effectually or take the place of a broken glass if necessary. It is best not to permit the gas to get into fire pits or engine rooms; these should be cut off from the space to be fumigated.

In case of a large range of houses opening into each other, it is best to separate them into several sections, by tacking up building paper or oiled cloth so that each section may be fumigated separately and at different times. The work may thus be done with greater ease and care, and with less danger to the plants. When all the larger cracks and openings have been stopped up, if the house is quite old or loose it is well to wet the roof on the outside just before fumigating. The water will fill the cracks between the glass and will assist in making the roof tight.

METHOD OF MAKING THE GAS.

The materials required are 98 per cent cyanide of potassium, broken in small lumps, best secured in 10 or 25 pound cans at 30 to 40 cents a pound, and commercial sulphuric acid at 3 to 4 cents a pound by the carboy.

For an ordinary house or frame, good vessels for liberating the gas are 1½ or 2-gallon earthern jars of as small diameter as possible so as to insure the immersion of the cyanide of potassium when it is dropped into the acid. One jar should be used to about every 25 feet in length of such houses as described, in order that the gas may be quickly distributed when set free. When the jars are placed in position the next step is to arrange the lower paper bags containing the desired amount of cyanide into the jars, from the outside. This is best done by passing a cord through a hook or screw-eye attached to the roof over each jar in such a manner that when the string or strings are loosened from the outside the bags of cyanide will be lowered into their respective jars, as shown in fig. 3. When the strings are ready, divide the amount of cyanide to be used into parts corresponding to the number of jars. Wrap each part up in a single thickness of ordinary newspaper and put in ordinary brown paper bags, and attach the bags to the strings, as shown in fig. 3. While the jars are empty test the arrangement to see if it works satisfactorily. After each bag is suspended in place, the other end of the string securely fastened where it can be reached from the outside, and the arrangement tested, move the suspended bags to one side so they will be out of the way while putting the water and acid in the jars. When this is done, pour into each jar an amount of water about equal to the bulk of the potassium cyanide in the bag. Eight ounces of cyanide will require about half a pint of water. The sulphuric acid should then be poured in until steam rises from the water. This would require for a pint of water about a pint and a half of acid. It is not necessary, however, to measure the acid as the evolution of steam indicates when the right amount has been poured in. Always put the water in first and then pour in the acid. As soon as this is done place the bags over their respective jars. When all is ready, go out, close the door, and carefully loosen the strings, allowing the bags to settle into

the acid. While the method just described is desirable for a large house or series of houses from which exit would be difficult after dark, it is not necessary to go to the trouble of lowering the cyanide into the acid by strings in most cases. When the jars containing the water and acid are properly placed, the cyanide in the paper sacks, as previously described, may be set beside the jars; then the operator, starting in one end of the house, may carefully drop the bag into the water and acid, coming out the other end of the house. If there are two sets of jars in different paths, it will be necessary for two operators to start, one in each path, working in the same direction, at about the same rate of speed. In this way the cyanide can be placed very quickly and easily in quite a large series of jars, taking care that no cyanide is

FIG. 3.—Violet house prepared for fumigation (original).

placed in a jar in such a way as to cut off the exit from the house of any operator. This method of hand dropping is now the one most largely used. The gas will very soon be given off and fill every portion of the house. It is colorless and smells and tastes like peach pits. A little of it is harmless, but too much will cause death. A small quantity will leak out of the house; avoid positions where it can be smelled. The time of exposure should be reckoned from the lowering of the cyanide into the jars. When the proper time has elapsed, varying for different plants as previously stated, quickly open the ventilators from the outside, so that the gas can escape as rapidly as possible. It will all be gone from a large house, such as described in this circular, in

half or three-quarters of an hour, and the ventilators may then be closed, if necessary. Next morning the material left in the jars should be emptied into a hole and buried. It is nothing but sulphate of potash, sulphuric acid, and water, having a little hydrocyanic acid gas in solution. The latter will soon disappear and the sulphuric acid will unite with lime in the soil, forming gypsum.

FUMIGATING BOXES.

For the purpose of experimenting and where only a few hundred plants are to be treated, a tight box may be made of 30 to 50 cubic feet capacity. The box should be as nearly air-tight as possible, with a removable cover and a small door at the bottom for introducing the cyanide of potassium into the bowl containing water and sulphuric acid, as shown in fig. 1.

The wire trays shown in the same illustration are used in fumigating cuttings of coleus or other plants. When desired the trays can be removed and pot plants set in the box and given such fumigation as desired. To prevent injury to the plants they should be so set that the foliage does not come within 18 inches of the bowl near the small door. When the plants are arranged the top is put on securely and a little water is poured into the bowl, and then sulphuric acid is added till steam is formed. The necessary amount of cyanide, wrapped in a small piece of newspaper, is then dropped into the bowl and the little door quickly closed. When the desired length of time has elapsed take off the cover and open the door and retire, so as not to breathe the gas. In a few minutes the gas will have sufficiently escaped so that the plants may be taken out and others treated in the same way. Injury (if there is any) to the plants may not show for two or three days, so, in the case of experimenting, conclusions should not be hastily drawn. The box may be used in the daytime if the work is done in a cool place. For experimental purposes and treating plants on a small scale, a small greenhouse containing 1,000 cubic feet, or less, is better than a box; as the results obtained with it are more reliable and there is less danger of injury to the foliage.

CONDENSED DIRECTIONS.

(1) Carefully determine the cubic contents of the house and the amount of cyanide of potassium to use.

(2) Make the house as tight as possible.

(3) Arrange so that the ventilators can be opened from the outside.

(4) Place the jars and strings in position.*

*If the potassium cyanid is to be dropped into the jars by hand place the package beside each jar; then a man for each separate group of jars should start at one end and work towards the other. After proper exposure open ventilators, etc.

(5) After dusk attack the bags containing the cyanide to strings, as described, and find if they work correctly.

(6) Hang the bags to one side and put water and acid into the jars; arrange protection and put the bags in place again.

(7) When all is ready lower the bags into the jars by loosening the strings from outside.

(8) After the proper exposure open the ventilators from outside, leaving them open from thirty to forty-five minutes before entering the house.

(9) Next morning bury contents of the jars.

(10) The foliage must be perfectly dry.

CAUTION.

It should be remembered that hydrocyanic acid gas is one of the deadliest poisons known, fatal to human beings and plants as well as to insects.

Greenhouses which are within 50 to 75 feet of dwellings should not be fumigated unless the windows and doors of the latter on the side next to the greenhouse can be closed during the operation.

It is essential that the exact proportion of cyanide be used at the rate designated for each cubic foot of space and that the exposure should not exceed the limit ascertained by experiments as appropriate to the plants to be fumigated. A greater strength of gas or a longer exposure than specified is apt to result in injury to the plants.

It is best to use this method at first experimentally on a small scale before attempting the fumigation of an entire greenhouse, and a preliminary test should always be made in case plants of a species or variety not previously fumigated are to be treated.

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Approved:

JAMES WILSON,
Secretary of Agriculture.

WASHINGTON, D. C., *October 2, 1903.*

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